

Modeling & Designing of A Novel Multilevel STATCOM With SVPWM Fed VSC For The Dynamic Stability Improvement Of A Grid-Connected Offshore wind Farm

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ABSTRACT:-This paper deals with the development of a Mat lab-simulink model of a new proposed scheme for grid connected off shore wind farm (OWF) and marine current farm (MCF) on a static synchronous compensator (STATCOM). The purpose of this simulation Model to getting better damping enhancement and voltage control by using a novel SVPWM technique. An equivalent Doubly fed Induction Generator is used here to operate the Off shore wind farm. To design a damping controller for this proposed scheme model control theory is used here for getting the effective characteristics. The proposed scheme of this AC bus system can easily control the voltage fluctuations. Power quality in distribution system has been the major issue now-a-days. Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of power quality problems like voltage sag, dynamic Stability service interruptions total harmonic distortion (THD) etc. Multi-level inverters are the best form to solve these problems. The general structure of multilevel inverter is to synthesize sinusoidal voltage waveform from several levels of voltages typically obtained from capacitor voltage source. In this paper Space Vector Pulse Width Modulation (SVPWM) technique is employed for the 5-level multi inverter and both these techniques are compared along with the application of STATCOM. It can be concluded from the simulated results that the proposed STATCOM joined with the designed damping controller is very effective to Balance the studied system under disturbance conditions.

KEYWORDS: off shore wind farm, marine current farm, Space Vector Pulse Width Modulation, STATCOM.

I. INTRODUCTION

Renewable energy is one of the hottest themes in the entire world today due to the fast and huge consumption of fossil fuels. Some academic researchers have devoted to high-capacity offshore wind turbine generators (WTGs) connected to onshore substations through undersea cables. Currently, wind doubly-fed induction generators (DFIGs) and wind permanent-magnet synchronous generators (PMSGs) have been widely used in high-capacity offshore wind farms (OWFs). From the historical point of view, a direct-coupled, modular PMSG for variable-speed wind turbines was proposed and multiple single-phase outputs were separately rectified to obtain a smooth dc link voltage. The dynamic model based on small-signal stability of a wind turbine (WT) using a direct-drive PMSG with its power converters and controllers was proposed. During the last decades, Wind Energy Conversion System (WECS) has grown dramatically. Variable-speed wind Turbines (VSWTs) attract considerable interest around the world, which is one of the solutions with the highest potential to reduce wind energy cost. The VSWT systems are usually based on doubly fed induction generators (DFIGs) or permanent magnet synchronous generators (PMSGs). Basically wind farm consists of many wind turbines that are connected with each other to produce small amount of electrical power that becomes powerful after connecting with the transformer. Areas that consists of the number of wind turbines for the sake of power generation from wind and are connected with each other in the different way is called wind farm. Basically wind farm

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consists of many wind turbines that are connected with each other to produce small amount of electric power. Different strategies are used to build the wind farms in different locations or area. Generators driven by marine-current turbine (MCT) combined with offshore generators driven by wind turbine (WT) will become a novel scheme for energy production in the future. Since oceans cover more than 70% surface of the earth, a hybrid power generation system containing both offshore wind farm (OWF) and marine-current farm (MCF) can be extensively developed at the specific locations of the world in the future. One of the simple methods of running an OWF is to connect the output terminals of several DFIGs together and then connect to a power grid through an offshore step-up transformer and undersea cables. To run an MCF may use several Permanent Magnets synchronous generators (PMSGs) connected directly to the power grid through an offshore step-up transformer and undersea cables.

II. RELATED WORK

A. DOUBLE FED INDUCTION GENERATOR (DFIG):

DFIG is an abbreviation for Double Fed Induction Generator, a generating principle widely used in wind turbines. It is based on an induction generator with a multiphase wound rotor and a multiphase slip ring assembly with brushes for access to the rotor windings. It is possible to avoid the multiphase slip ring assembly, but there are problems with efficiency, cost and size. A better alternative is a brushless wound-rotor doubly-fed electric machine. Figure 1 indicates the doubly fed induction generator model. DFIG is of great advantage, and is widely used in large capacity wind turbines in recent years.

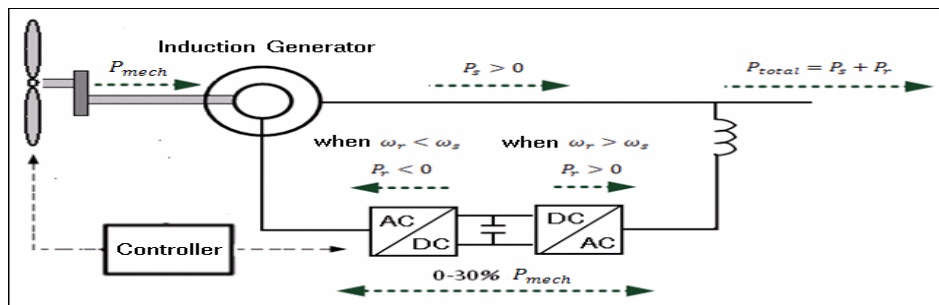


Fig.1. Doubly Fed induction generator model

B. PITCH ANGLE CONTROL

When V_w is lower than the rated wind speed of the WT (V_{Wrated}), $\beta_w = 0$. When $V_w > V_{Wrated}$, the Pitch-angle Control System of the WT activates and the pitch angle of the WT (β_w) increases. The control system structure used to generate the pitch angle reference is depicted in Figure 2. The pitch controller consists of a nonlinear feed forward path, which generates β and a linear feedback path, which generates $\Delta\beta$.

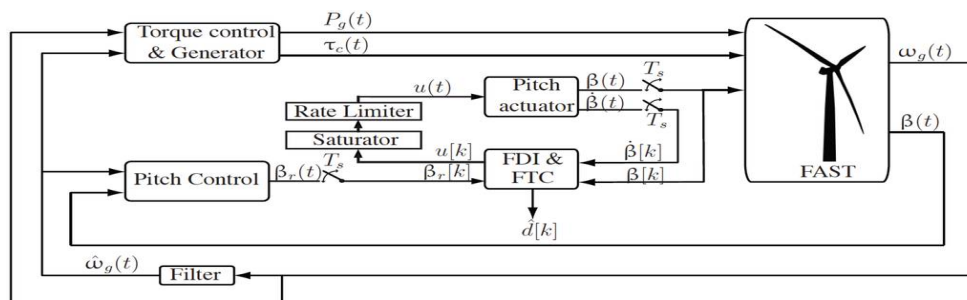


Fig.2. Block diagram of the pitch-angle control system of the studied WT.

C. STATCOM MODEL

In order to temporarily avoid the high level of reactive compensation during recovery. In addition to the normal STATCOM control, allows for torque transient alleviation during the recovery process after a grid fault. This is possible to achieve by reducing the voltage reference of the STATCOM control system and, by that, the reactive compensation when stability is ensured after fault clearing but before the grid voltage and the speed of the generator have returned to the pre-fault values. In this way, the STATCOM can improve the torque capability of the DFIG when this is needed keep the system stable, and once stability is ensured, it can reduce the maximum torque during recovery. The strain on the drive train can thereby be reduced. This is particularly relevant where wind turbines cannot just disconnect from the grid to protect the installation from risk of mechanical damage that might be caused by the cumulative stress of repeated peak torque transients This paper focuses on the recovery process after fault clearing and reactive power compensation .The other main issue related to this concept is that, since the decelerating torque of the generator is limited, the recovery process of the system will be longer than for the case of normal control of the STATCOM with a fixed voltage reference value.

D. CASCADE H-BRIDGE MULTILEVEL INVERTER

A three-phase structure of a five-level cascaded inverter is illustrated in Figure 3. The multilevel inverter using cascaded-inverter with separate dc sources (SDCSs) synthesize a favorable voltage from several independent sources of dc voltages, which may be achieved from batteries, solar cells and fuel cells [6]. This structure recently has become very widespread in ac power supply and adjustable speed drive applications.

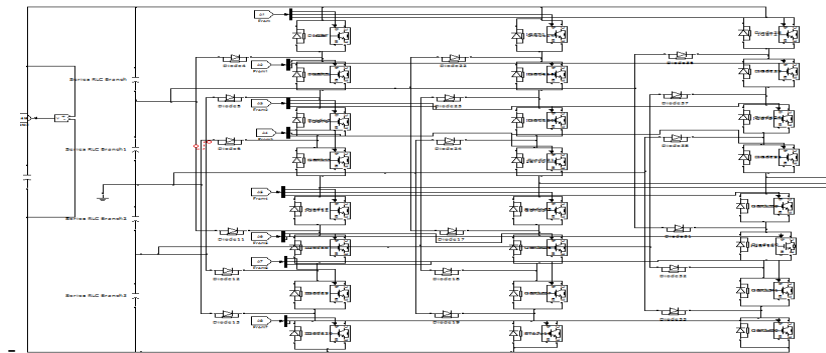


Figure 3. Five level cascade H-bridge inverter structure

The output of each cell will have three levels $+V_{dc}$, 0 and $-V_{dc}$ that obtained by connecting the dc source to the ac output by different combinations of the four switches S1 , S2 , S3 and S4 . To obtain $+V_{dc}$, switches S1 and S4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S2 and S4 . By turning on S1 and S2 or S3 and S4 , the output voltage is 0. The output voltage is the sum of the voltage that is generated by each cell. The numbers of output voltage levels are $2(m + 1)$ where m is the number of cells. The output voltage of a cascaded H-bridge inverter leg is obtained by adding the single H-bridge output voltages as follows:

$$V_o(t) = \sum_{k=1}^n v_{o_k}(t) \quad (1)$$

where k is number of k th cell. The voltage level and switching state of the five-level CHB inverter are shown in the Table 1. Table 2 shows the component requirements for m -level cascade H-bridge inverter for a three-phase setup.

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Table 1. Switching state for five level cascade H-bridge inverter

Switching State								
S_1	S_2	S_3	S_4	S'_1	S'_2	S'_3	S'_4	V_{ao}
1	0	1	0	0	1	0	1	$2V_{dc}$
1	1	1	0	0	0	0	1	V_{dc}
1	0	0	0	0	1	1	1	V_{dc}
1	0	1	1	0	1	0	0	V_{dc}
0	0	1	0	1	1	0	1	V_{dc}
1	1	1	1	0	0	0	0	0
1	1	0	0	0	0	1	1	0
1	0	0	1	0	1	1	0	0
0	1	1	0	1	0	0	1	0
0	0	1	1	1	1	0	0	0
0	0	0	0	1	1	1	1	0
0	1	1	1	1	0	0	0	$-V_{dc}$
0	0	0	1	1	1	1	0	$-V_{dc}$
0	1	0	0	1	0	1	1	$-V_{dc}$
1	1	0	1	0	0	1	0	$-V_{dc}$
0	1	0	1	1	0	1	0	$-2V_{dc}$

Table 2. Component requirements for m-level cascade h-bridge inverter

<i>m</i> -Level Cascade H-Bridge	Number of elements
DC bus capacitors	$3(m-1)/2$
Main diodes	$6(m-1)$
Main switches	$6(m-1)$
Clamping diodes	0
Clamping capacitors	0

Figure 4 shows an example phase voltage waveform For a five-level cascaded H-bridge inverter with four dc source. The main advantages and disadvantages of the cascade H-bridge multilevel inverter are as follows:

Advantages:

- Requires a low number of components per level.
- Possibility to implement soft-switching.
- Uncomplicated voltage balancing modulation.
- Modularized structure without clamping component.

Disadvantages:

- Needs separate isolated dc sources for real power transfer.
- No common DC-bus.

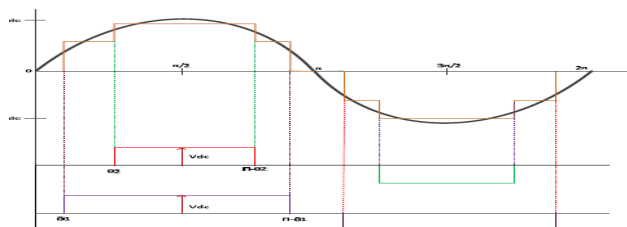


Figure 4. Output voltage waveform for five level cascade H-bridge inverter

E. Five-Level Cascade H-Bridge Inverter Based STATCOM

In this study, five-level cascade h-bridge inverter is presented for power circuit of DSTATCOM. Power circuit of DSTATCOM based five-level cascade H-bridge inverter is illustrated in Figure 5.

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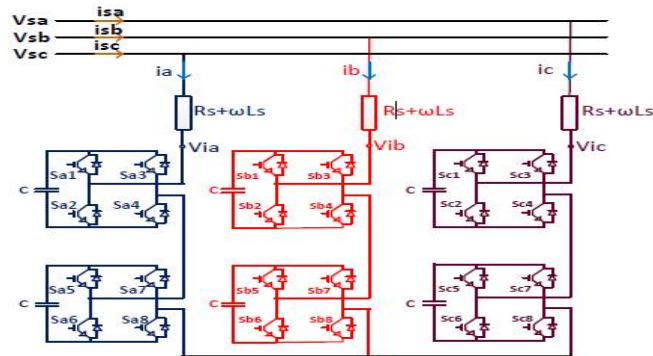


Figure 5. STATCOM five level cascade H-bridge inverter

D-STATCOM consists of six h-bridge cells, six dclink capacitors C that providing the dc voltages to Hbridge cells and a coupling inductance with internal resistance $\omega L_s + R_s$ connecting to AC grid the inverter. From Figure 6, AC circuit equations of DSTATCOM in the stationary reference frame can be acquired as follows

$$L_s \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + R_s \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} - \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix}$$

$$\bar{V}_s = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad \text{and} \quad \bar{V}_i = \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix} \quad (2)$$

V_s, V_i respectively are defined as complex voltage vector of network and complex voltage vector of inverter. Space vector theory based on synchronous reference frame is exerted to DSTATCOM. Coordination of space vector is shown in Figure 6. Stationary reference and synchronous rotating frame are respectively shown with $\alpha\beta$ and dq-axes.

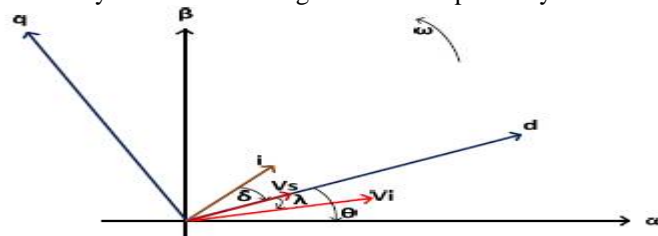


Figure 6. Coordinate system for synchronous rotating reference frame

Current vector and voltage vectors in complex plane are representing in stationary reference frame as follows

$$\bar{V}_i = V_{ia} + V_{ib} e^{j\varphi} + V_{ic} e^{j2\varphi} = V_i e^{j(\theta-\lambda)}$$

$$\bar{V}_s = V_{sa} + V_{sb} e^{j\varphi} + V_{sc} e^{j2\varphi} = V_s e^{j(\theta)}$$

$$\bar{i} = i_a + i_b e^{j\varphi} + i_c e^{j2\varphi} = i e^{j(\delta+\theta)} \quad (3)$$

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where $\phi = 2\pi / 3$, $V_s(a,b,c)$ and $V_i(a,b,c)$ respectively are instantaneous phase voltages of power system and STATCOM. The d-axis of the space vector figure and V_i are assigned together. By multiplying complex vectors in the stationary reference frame with unity space vector $e^{-j\theta}$ can transformed them into synchronous rotating as follows

$$L_s e^{-j\theta} \frac{d}{dt} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} + R_s e^{-j\theta} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} = \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} e^{-j\theta} - \begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix} e^{-j\theta}$$

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} e^{-j\theta} = v_{sd} + jv_{sq}$$

$$\begin{bmatrix} V_{ia} \\ V_{ib} \\ V_{ic} \end{bmatrix} e^{-j\theta} = v_{id} + jv_{iq} = v_i \cos \lambda - jv_i \sin \lambda$$

$$\begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} e^{-j\theta} = i_d + ji_q \tag{4}$$

$$L_s \frac{di_d}{dt} + R_s i_d = v_{sd} - v_i \cos \lambda + L_s \omega i_q$$

$$L_s \frac{di_q}{dt} + R_s i_q = v_{sq} - v_i \sin \lambda - L_s \omega i_d \tag{5}$$

$$P_c = V_{dc} I_{dc} = \frac{3}{2} (v_{id} i_d + v_{iq} i_q)$$

where I_{dc} is the capacitor current. (6)

III. SYSTEM IMPLEMENTATION

A. MODELS OF THE OFF SHORE WIND FARM AND MARINE CURRENT FARM

Figure 7, shows the structure of the studied integrated DFIG based OWF and PMSG based MCF with the proposed STATCOM. The 80MW OWF is represented by a large equivalent aggregated DFIG driven by an equivalent aggregated variable speed WT through an equivalent aggregated gearbox. The 40MW MCF is represented by a large equivalent aggregated PMSG driven by an equivalent aggregated variable speed MCT through an equivalent aggregated gearbox. The OWF, the MCF, the STATCOM and a local load are connected to an AC bus that is fed to the onshore power grid through an offshore step-up transformer and undersea cable. The employed mathematical models of the studied system are described as below.

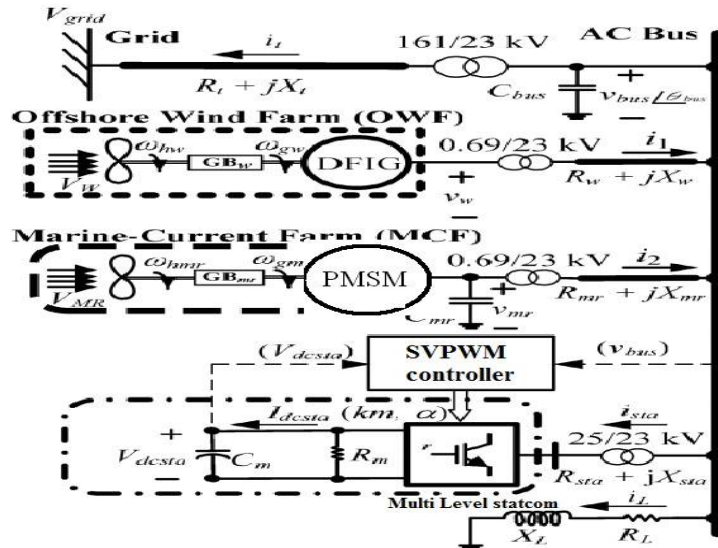


Fig. 7. Configuration of the integrated OWF, MCF & SVPWM with Five level STATCOM.

IV. SIMULATION MODEL AND RESULT

B. SIMULINK DIAGRAM:

Figure.8, shows the Simulink Diagram of the Proposed System. By keeping the wind speed at 12 m/s and marine current speed at 2.5 m/s a three-phase fault is applied at the grid.

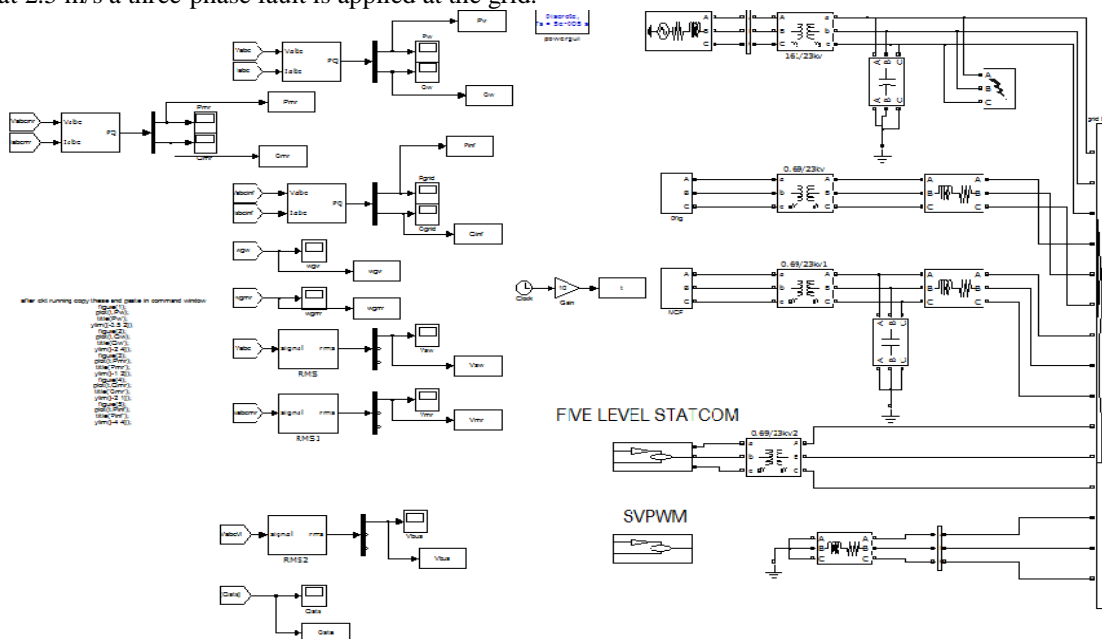


Fig. 8. Simulink Diagram of the Proposed System

Three-Phase Short-Circuit Fault at Power Grid

Fig. 9 plots the transient responses of the studied system with and without the proposed STATCOM joined with the designed PID damping controller under a three-phase short-circuit fault at the grid. The OWF operates under a base wind speed of 12 m/s while the MCF operates under a base marine-current speed of 2.5 m/s. A three-phase short-circuit fault is suddenly applied to the grid at $t=1s$ and is cleared at $t=1.25s$ in Fig. 9 that most quantities suddenly drop to low values when the fault occurs. When the fault is cleared, all responses shown in Fig.9 stably return the original steady-state operating conditions within 4s. The proposed STATCOM with the designed PID damping controller can offer better damping characteristics to the studied system under the severe three-phase short-circuit fault than without the PID controller.

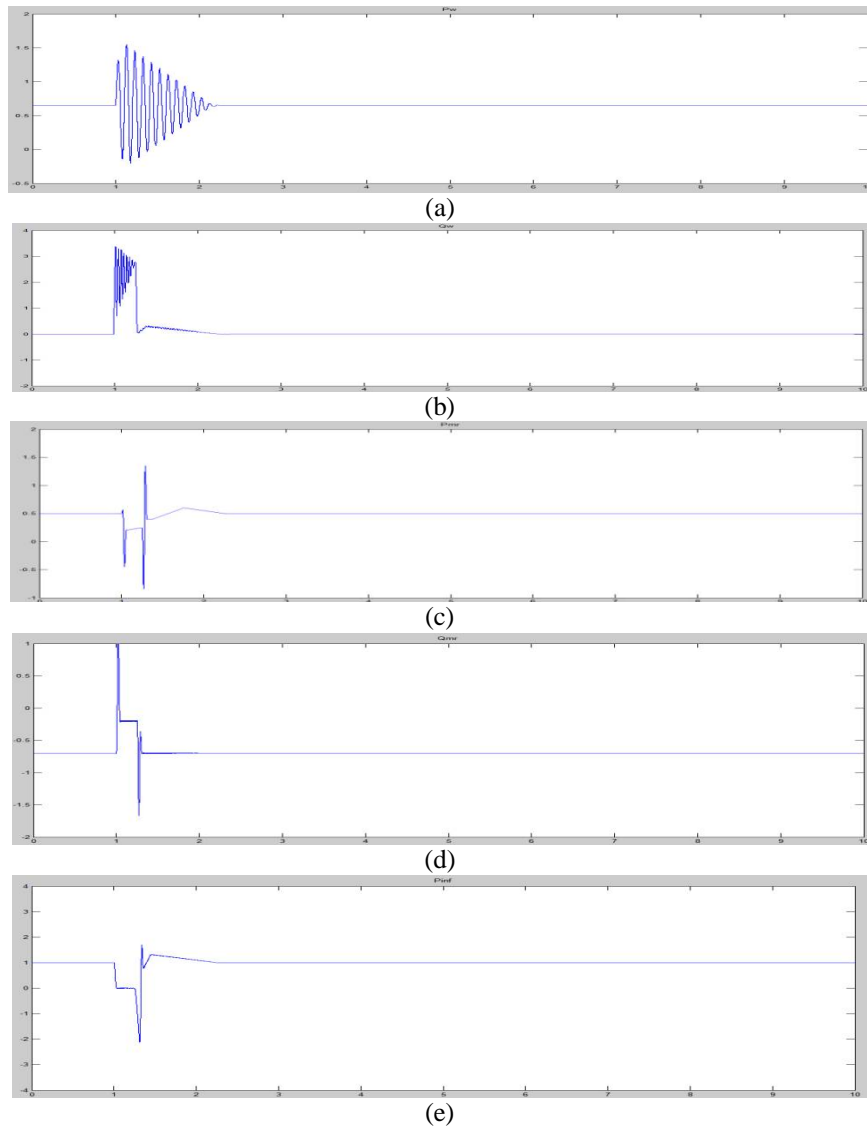


Fig.9. Transient responses of the studied system with and without the designed PID STATCOM damping controller under a three-phase fault at power grid (a) Pw,(b)Qw,(c)Pmr,(d)Qmr,(e)Pgrid

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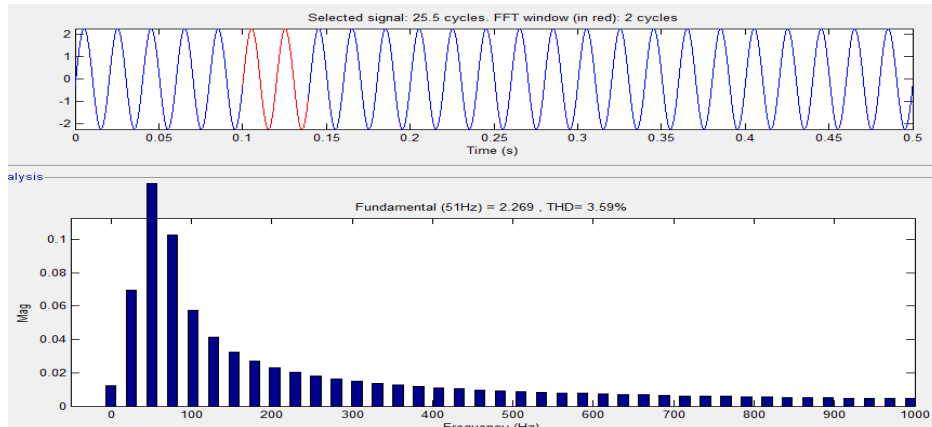


Fig: 10 thd of 3 level Statcom

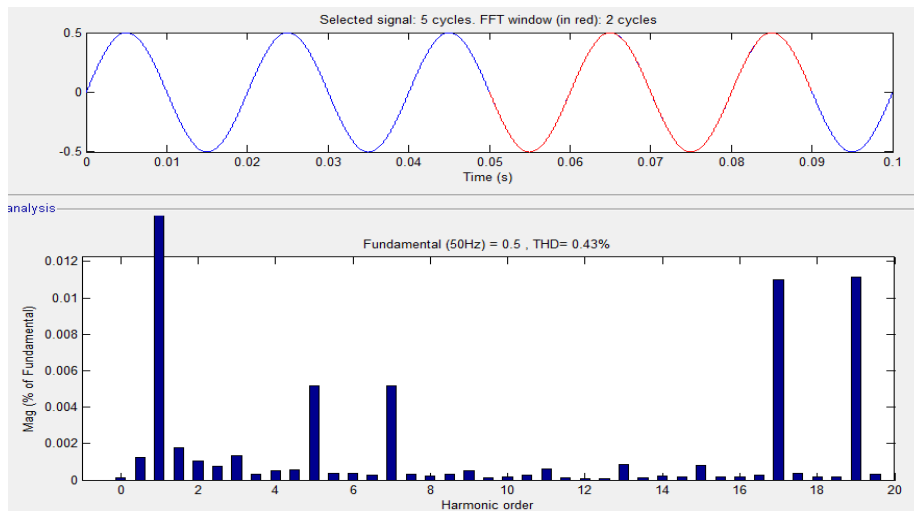


Fig: 11 thd of 5 level Statcom

Device connected	Power factor	T.H.D	Compensated voltage	Compensated current
Without compensator	0.62	38.5	0v	0v
With 2 level STATCOM	0.69	37.8	264v	6.5A
With 3 level STATCOM	0.92	3.69	264v	7.2A
With 5 level STATCOM	0.89	0.43	264v	10.3A

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V. CONCLUSION

In this paper, a STATCOM based five-level CHB inverter in order to improve the power quality is studied. The advanced phase shift pulse width modulation technique is used for five-level CHB inverter. In this study, a voltage change every moment in the consumer side but STATCOM was able to keep the voltage consumer side in 1 pu. The controller that is used in STATCOM is a simple and popular one and it compares i_q and i_d with their original amounts in order to produce V_d and V_q . The THD of inverter output current was achieved in the low switching frequency. Simulation results show that the proposed STATCOM. This paper has presented the dynamic stability improvement of an integrated OWF and MCF using a STATCOM. A PID damping controller has been designed for the STATCOM by using a novel approach based SVPWM based multi statcom simulations of the studied system subject to a noise wind-speed disturbance, a marine- current speed disturbance, and a three-phase short-circuit fault at the grid have been systematically performed to demonstrate the effectiveness of the proposed STATCOM joined with the designed PID damping controller on suppressing voltage fluctuation of the studied system and improving system dynamic stability under different operating conditions.

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